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(54) Title: METHOD OF MAKING DISPERSION DECREASING AND DISPERSION MANAGED OPTICAL FIBER

(57) Abstract

The invention is a method of making an optical fiber or cane (600) that has optical properties that vary axially. Core glass (100) and clad glass (200) are fed into a furnace to form the cane or fiber. The velocities of the feeding of the clad and core are controlled so that the total combined mass per unit time is constant. The diameter of the core (604) varies along the length of the fiber or cane in accordance with the control of the velocities. The variance in the core diameter results in the variance of the axial optical properties of the fiber or cane.
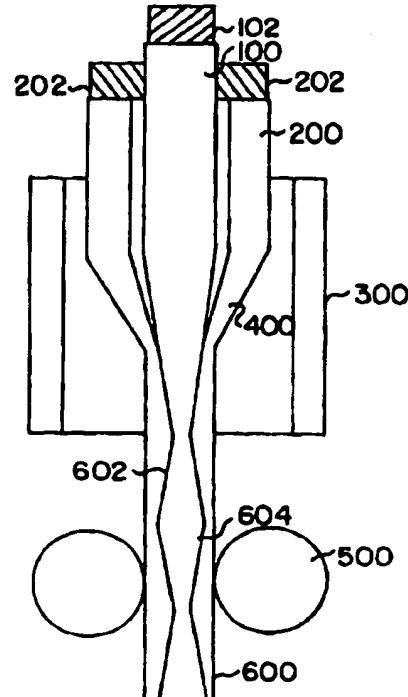
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METHOD OF MAKING DISPERSION DECREASING
AND DISPERSION MANAGED OPTICAL FIBER

Background of the Invention

This invention relates to methods of making
optical fiber having longitudinally varying optical
properties. Optical fibers made in accordance with the
invention may include dispersion decreasing and
dispersion managed fiber. Such fibers may be used for
soliton pulse transmission, in which an optical soliton
pulse maintains its original shape as it travels along
the optical fiber. However, the invention is not
limited to this application.

Dispersion refers to the spreading out of light
pulses as they travel in an optical fiber. Such
spreading of a soliton pulse causes attenuation losses
as the pulse travels along the fiber. Dispersion may be
compensated for by changing the optical properties of
the fiber so as to reduce the total dispersion. Two
types of fiber which compensate for dispersion are
dispersion decreasing fiber and dispersion managed
fiber.

Dispersion decreasing fiber has a slow change in
dispersion over the length of the fiber. This gradually
decreases the dispersion in the fiber and thus decreases
the effect of attenuation losses on the transmission of
a soliton pulse traveling along the fiber.

Dispersion managed fiber is characterized by
sections of positive and negative dispersion, with

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relatively sharp transitions between each section.
Dispersion managed fiber strives to create a fiber where
the overall dispersion of the fiber is zero, but the
dispersion at any one point is either slightly positive
or negative. Such a scheme minimizes the effects of
four-wave mixing, self phase modulation and other
nonlinear optical effects that are produced by
transmitting data pulses at the zero dispersion point,
while still effectively compensating for the chromatic
dispersion effects that occur over the length of the
fiber link.

    The present invention is directed to methods of
making dispersion decreasing and dispersion managed
fiber by axially changing the optical properties of the
fiber.

    Prior art methods of making fiber, having axially
changing optical properties, each have associated
disadvantages. For example, changing the core-clad
ratio, by either machining or chemically etching the
consolidated preform or core cane, alters the optical
properties of the fiber. Unfortunately, this method
adds additional processing steps and additional select
losses associated with these steps. Changing the draw
tension may also change the optical properties of the
fiber axially, but, this method fails to maintain the
advantages of drawing fiber in a particular tension
regime. Another alternative, altering the optical
properties of the fiber by drawing a fiber having a non-
constant outer diameter, creates unwanted
connectorization and splicing issues. Theoretically,
the optical properties of the fiber can be changed by
placing multiple overclad compositions on the fiber to
obtain stress effects in the drawn fiber. However this
method would alter the existing laydown and
consolidation processes to such an extent that it would

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not likely provide a viable manufacturing process.

Thus, there is a need for a method of changing the optical properties of fiber that does not have the disadvantages associated with these prior art methods.

5   Summary of the Invention

It is an object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber without additional manufacturing steps or the select losses associated with
10   such additional steps.

It is a further object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber which maintains a particular tension regime during the draw process.

15   It is an object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber having a constant outside diameter.

It is a further object of the present invention to
20   provide a method of making dispersion decreasing and dispersion managed fiber which does not alter existing laydown and consolidation processes.

It is an object of the present invention to provide a method of making dispersion decreasing and
25   dispersion managed fiber which allows the axial location of change in the dispersion in the fiber to be determined.

The disadvantages and limitations of other methods of changing the optical properties of fiber are overcome
30   by the present invention, which provides a method for separately controlling and varying the input, into a furnace, of core and clad material, and thereby controlling the core diameter of the product which exits

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the furnace, i.e. either core or fiber, e.g. by drawing
a rod and tube simultaneously using separate downfeeds.

Brief Description of the Drawings

The above and other objects and advantages of the
invention will be apparent upon consideration of the
following detailed description, taken in conjunction
with the accompanying drawings, in which like reference
characters refer to like parts throughout, and in which:
FIG. 1 is a diagram showing an illustrative
embodiment of a method of making Dispersion Decreasing
and Dispersion Managed Fiber in accordance with the
present invention; and
FIG. 2 is a block diagram of a control system of
the present invention.

Detailed Description of the Invention

The method of the present invention includes
mounting (1) a rod containing core glass and possibly a
material amount of cladding glass, and (2) a tube of
cladding glass, on separate downfeeds going into a draw
furnace such that the rod is within the tube. (As those
skilled in the art will recognize, "core" glass has a
higher refractive index than "clad" glass.) The rod and
tube are lowered through the furnace and combine to form
a fiber which is drawn from the furnace. The velocity
of each downfeed is separately controlled and
coordinated such that the mass per unit time of glass
passing through the furnace remains constant, while at
the same time varying the amount of rod and tube
material passing through the furnace.
The resultant fiber (or cane) drawn from the
furnace has a constant outside diameter. However, the
diameter of the core of the fiber varies along the
length of the fiber in accordance with the variance of

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the amount of tube or rod material passing through the furnace. It is the resulting variance in the core diameter of the fiber which provides axial variation of the optical properties of the fiber.

In making dispersion decreasing fiber, the variance in the diameter of the core is very gradual, to allow for a slow change in dispersion along the length of the fiber. The making of dispersion managed fiber requires more abrupt changes in the diameter of the core of the fiber to create sections of positive and negative dispersion fiber with relatively sharp transitions between each section. Both gradual and abrupt changes in the core diameter of the fiber may be obtained through the process of the present invention.

FIG. 1 is a generalized illustration of the fiber drawing process of this invention. The rod 100, consisting of all core material and possibly a material amount of cladding is mounted on a downfeed 102. The tube 200, which consists entirely of cladding glass, is mounted on a separate downfeed 202. The clad glass of the tube 200 may be pure silica. A control system 204 may be operated manually or automatically to control the velocity of the downfeeds 102 and 202. The control system 204 includes a programmable controller which includes two motors (not shown), in which the first motor is connected to downfeed 102 and the second motor is connected to downfeed 202. The control system 204, with the use of the motors, controls the velocity of the downfeeds 102 and 202. In controlling the velocity of the downfeeds 102 and 202, the control system 204 insures that the mass per unit time of glass passing through the furnace remains constant, while at the same time varying the amount of rod 100 and tube 200 passing through the furnace 300. The programmable computer is programmed with the desired variation of the core

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diameter, as a function of fiber length, and receives a
feedback signal from the fiber draw system representing
draw speed.

5   The rod 100 and the tube 200 combine in the
furnace 300 to form a fiber or cane 600. Cane is
thicker and sturdier than fiber, includes an inner core
region and a surrounding clad and may later be overclad
and drawn into fiber. My invention is applicable both
to making fiber or cane. However, by way of
10   illustration, my invention is primarily described herein
with reference to making fiber. The fiber or cane 600
is drawn from the furnace by a set of tractors 500.

The principle of operation of the invention is as
follows. At steady state, the total amount of glass
15   going into the draw as rod 100 and tube 200 is equal to
the amount of glass coming out as fiber 600. This can
be represented by the following equation:

$$A_{rod}V_{rod} + A_{tube}V_{tube} = A_{fiber}V_{fiber}$$

where V_x = the velocity of the component x; and
20   A_x = the cross sectional area of component x.

The diameter of the core of the fiber, D_{core} may be
described by the following equation:

$$D_{core} = D_{fiber} * Kf A_{rod}V_{rod}/(A_{rod}V_{rod}+A_{tube}V_{tube})$$

where D_{fiber} = fiber diameter;
25   K = the ratio of the area of the fiber to the sum of
the areas of the rod and the tube; and
f = the ratio of the area of the core diameter to the
outer diameter of the fiber.

The outside diameter of the fiber, D_{fiber}, may be
30   described by the following equation:

$$D_{fiber} = 2 * \sqrt{\frac{(A_{rod}V_{rod}+A_{tube}V_{tube})}{V_{fiber}\pi}}$$

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Combining the equation for D_{core} and D_{fiber} gives the
following expression for D_{core}:

$$D_{core} = \frac{2Kf\,A_{rod}V_{rod}}{\sqrt{V_{fiber}(A_{rod}V_{rod}+A_{tube}V_{tube})\pi}}$$

Each of the terms of this equation can be varied over
time. Desirably, the dimensions of the rod and the
5   tube, as they are fed into the furnace, remain constant.
It is also desirable that the fiber drawn from the
furnace has a constant outside diameter. Therefore,
when these factors are constant, K and f are constants.
An inspection of the equation for D_{fiber} shows that in
10   order for D_{fiber} to remain constant while D_{core} varies, at
least two of the terms must be varied. (Although
constant outside diameter is not required for optical
properties, it is a desirable attribute for cabling,
connecting and splicing.)
15   Examination of the equation for D_{core} as a function
of time shows that D_{core} can be varied in a variety of
ways to obtain a fiber having a constant outside
diameter. In theory, any two of the variables, A_{rod},
A_{tube}, V_{rod}, V_{tube} or V_{fiber} could be modulated in such a way
20   to produce a fiber having a constant outside diameter.
This invention is directed towards those combinations of
variables that do not require changing A_{rod} or A_{tube}.
Using the approach of changing only draw speeds or
downfeed speeds makes it possible to correlate changes
25   in the fiber with changes in draw or downfeed speed,
that would not be as easily done with changes in A_{rod} or
A_{tube}.
Three possible combinations of velocities can be
varied over time: $V_{fiber}V_{rod}$; $V_{tube}V_{rod}$, and $V_{fiber}V_{tube}$. Varying
30   $V_{rod}V_{tube}$ while holding V_{fiber} constant requires that the
mass per unit time of glass passing through the furnace

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be constant, so there is little or no change in the
shape of the root 400 that is normally associated with
changes in fiber draw speed. This minimizes unsteady
state behavior and makes it easier to control the
5   process. This approach also makes it easier to
determine where the changes in the core diameter occur
in a fiber by correlating changes in downfeed speed to
the length of fiber drawn. There is some lag time
between when the downfeed change is made and when the
10   drawn fiber actually starts to change, but under the
relatively steady state condition provided by holding
V_{fiber} constant, this lag time is fairly constant. This
also cuts down on waste which in turn makes the
manufacturing of dispersion decreasing and dispersion
15   managed fiber easier and more cost effective.
        A block diagram of a control system which may be
used in the present invention is set out in FIG. 2. The
control system may be implemented using conventional
components which perform the designated computational
20   functions, e.g. a computer. In this control system,
A_{rod}, A_{tube}, K and f are constants, as the chemical and
physical composition of the rod and tube and their cross
sectional dimensions, do not vary substantially along
their length. The diameter of the fiber, D_{fiber}, is set
25   based on the specification of the fiber. A typical
value in telecommunication fibers is 125 μm. V_{fiber} is
set or controlled based on the capacity of the draw, and
the ability to adequately control any secondary
processes, such as coating application in the case of
30   fiber. In general, V_{fiber} is set as high as possible,
while still maintaining control of the process to
maximize draw capacity. The value of D_{core} is determined
based on the dispersion target for the particular fiber
being made and is provided to the control system from
35   the programmable computer. For example, to produce a

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dispersion decreasing fiber, D_{core} would be slowly
decreased over a length of fiber tens of kilometers in
length. To produce dispersion managed fiber, the core
diameter would be increased and then decreased, as
indicated in Fig. 1 by the core portions 602 and 604.
The calculation determining the waveguide dispersion may
be done separately from the actual control process or
directly in the control loop by the determination of
D_{core}. The calculation may also be incorporated into the
control scheme in which case the waveguide dispersion
would be an independent variable and D_{core} would depend on
the waveguide dispersion. My invention allows the
production of a fiber or cane having a core diameter
which varies linearly or non-linearly as a function of
length.

Once D_{fiber}, V_{fiber} and D_{core} are established, V_{rod} is
calculated from the following equation, which can be
derived from the steady-state mass balance and the
expression for D_{core} previously shown:

$$V_{rod} = \Pi D_{fiber} V_{fiber} D_{core} / K f^2 A_{rod}.$$

Once V_{rod} has been determined, V_{tube} is calculated
from the overall mass balance through the furnace:

$$V_{tube} = (V_{fiber} D^2_{fiber} \Pi - A_{rod} V_{rod}) / A_{tube}.$$

To produce a dispersion decreasing fiber D_{core} would
be slowly decreased as the rod and tube were drawn into
the fiber. As D_{core} is decreased, V_{rod} will be decreased
by a factor of:

$$\Pi D_{fiber} V_{fiber} / K f^2 A_{rod}.$$

At the same time, V_{tube} will increase by the factor
A_{rod}/A_{tube}, thereby maintaining a constant mass balance in
the furnace.

Similar control schemes may be used for the cases
where V_{tube} is held constant and V_{fiber} and V_{rod} are varied,
or where V_{rod} is held constant and V_{fiber} and V_{tube} are
varied. In the case described above, it is also

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possible to reverse the calculation of V_{tube} and V_{rod}, such that V_{tube} is a function of D_{core} and V_{rod} is calculated from the mass balance.

Thus a method for creating dispersion decreasing and dispersion managed fiber is provided. Although particular illustrative embodiments have been disclosed, persons skilled in the art will appreciate that the present invention can be practiced by other than the disclosed embodiments, which are presented for purposes of illustration, and not of limitation, and the present invention is limited only by the claims that follow.

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WHAT IS CLAIMED IS:

1.   A method of making optical fiber or cane
having a core and surrounding cladding, which comprises:
        supplying core glass material and cladding glass
material to a furnace;
        varying the volumetric ratio of said core glass
material to said cladding glass material passing through
the furnace;
        combining said core glass material and said
cladding glass material in the furnace; and,
        drawing from the furnace an optical fiber or cane
which has a constant diameter.

2.   The method of claim 1 wherein the optical
fiber or cane is drawn at a constant speed.

3.   The method of claim 2 wherein the diameter of
the optical fiber or cane continuously decreases.

4.   The method of claim 2 wherein the diameter of
the optical fiber or cane continuously increases.

5.   The method of claim 2 wherein the diameter of
the core of the optical fiber or cane alternates between
decreasing with length and increasing with the length
of fiber or cane drawn.

6.   A method of making optical fiber or cane
having a core and surrounding cladding, which comprises:
        feeding core glass and cladding glass into a
furnace;
        providing a signal representing a desired
variation in the diameter of the core of the resulting
fiber or cane in response to said signal;

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in response to said signal, varying the volumetric
ratio of said core glass material to said claddding
glass material passing through the furnace;
       maintaining a constant volumetric flow of glass
5   through the furnace;
       combining said core glass material and said
cladding glass material in the furnace; and,
       drawing from the furnace an optical fiber or cane
which has a constant diameter.

10   7.   The process of claim 6 where said varying
step is comprised of the steps of:
       in response to said signal, varying the rate at
which said core glass is feed into the furnace;
       generating a second signal representative of the
15   rate at which said core glass is feed into the furnace;
and
       in response to said second signal, varying the
rate at which said clad glass is feed into said furnace.

       8.   The process of claim 6 where said varying
20   step is comprised of the steps of:
       in response to said signal, varying the rate at
which said clad glass is feed into the furnace;
       generating a second signal representative of the
rate at which said clad glass is feed into the furnace;
25   and,
       in response to said second signal, varying the
rate at which said core glass is feed into said furnace.

       9.   A method of making optical fiber or cane
having a core and surrounding cladding, which comprises:
30   providing a glass tube which is comprised of
cladding glass;

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       providing a glass rod which comprised of core glass;

       placing said rod in said tube;

       attaching one end of said rod to a first drive

5   means;

       attaching one end of said tube to a second drive means;

       lowering the other end of said rod and tube into a furnace;

10   independently varying the rate of lowering of said rod and said tube into the furnace so that the ratio of rod material to tube material fed into the furnace varies;

       drawing an optical fiber or cane from said furnace

15   which has a constant outer diameter and a varying core diameter.
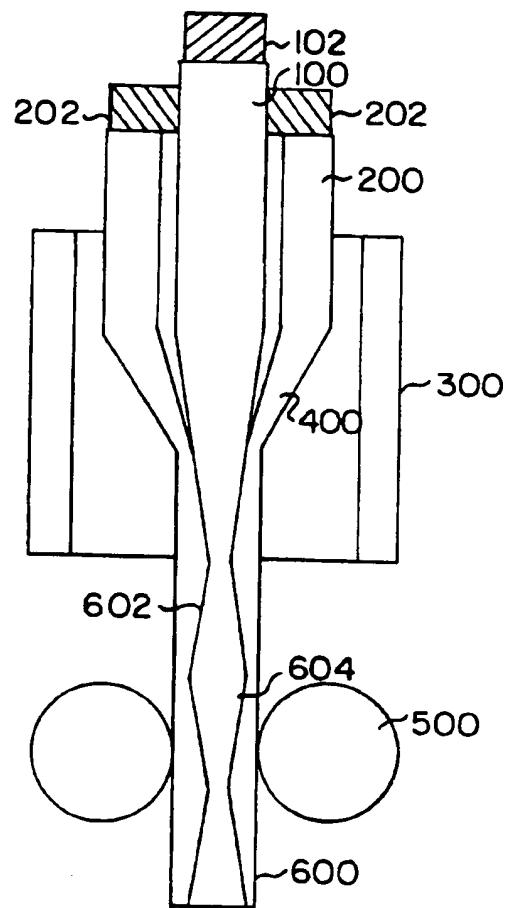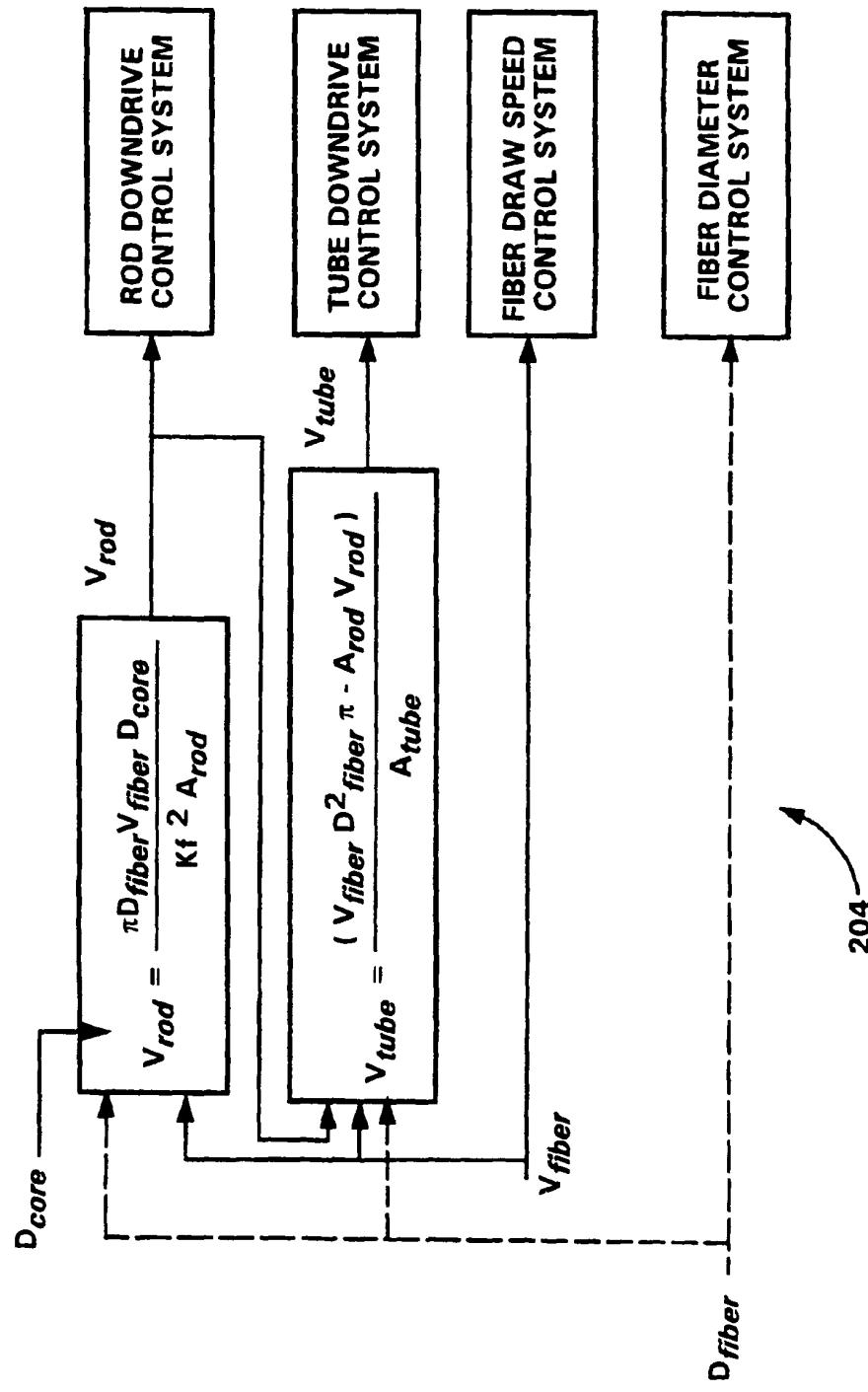
FIG.1

FIG.2

$$V_{rod} = \frac{\pi D_{fiber} V_{fiber} D_{core}}{K_f{}^2 A_{rod}}$$

$$V_{tube} = \frac{(V_{fiber} D^2{}_{fiber} \pi - A_{rod} V_{rod})}{A_{tube}}$$

ROD DOWNDRIVE CONTROL SYSTEM

TUBE DOWNDRIVE CONTROL SYSTEM

FIBER DRAW SPEED CONTROL SYSTEM

FIBER DIAMETER CONTROL SYSTEM

D_{core}

V_{rod}

V_{tube}

V_{fiber}

D_{fiber}

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A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C03B 37/027, 37/07, 37/075
US CL :65/381, 377, 402, 412

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 65/381, 377, 402, 412

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,E	US 5,613,028 A (ANTOS et al) 18 March 1997, col. 4, lines 21-40.	1,2,5-9
A	US 4,578,096 A (SIEGMUND) 25 March 1986.	
A	JP 405178634 A, (NAKAYAMA) 20 July 1993.	

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

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